Disturbance dynamics of forested ecosystems

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Introduction

Forested ecosystems are dynamic, subject to natural developmental processes as well as natural and anthropogenic stresses and disturbances. Degradation is a related term, for lowered productive capacity from changes to forest structure of function (FAO, 2001). Degradation is not synonymous with disturbance, however; disturbance becomes degradation when natural resilience mechanisms are overwhelmed (Stanturf, 2004). Although ecologists have long recognized disturbance as a phenomenon, only in the last 30 years has it been accorded a place in theories of ecosystem dynamics (Pickett and White, 1985). Disturbance is more the norm than the exception in forested ecosystems, is common to many spatial and temporal scales, at all levels of ecological organization. My objective in this paper is to pose three questions about disturbance, and offer my perspective as incomplete answers. These questions are (1) Why do/should we care about disturbance dynamics of forests? (2) What exactly are disturbance dynamics? and (3) How can we incorporate disturbance dynamics into forest management?

Why Is Knowledge of Disturbance Dynamics Important?

Forest management today is conducted within a context of sustainability that goes beyond the traditional notion of sustainable yield (Stanturf *et al.*, 2003) to encompass intergenerational equity and cultural values that include biodiversity and long-term site productivity. Disturbances, whether natural or anthropogenic, affect forest structure, composition, and ecological processes, which affects productivity, biodiversity, and provision of environmental goods and services. In addition to "normal" levels of disturbance, there is accumulating evidence for changing responses to disturbance, that thresholds have been reached where recovery trajectories are different than were experienced historically. Partly this is due to more pervasive anthropogenic impacts (Goudie, 1986). Climate change is increasingly likely, adding to the specter of compound disturbances resulting in surprising responses of forested and other ecosystems (Paine *et al.*, 1998). Forest management tends toward intervention when a major disturbance occurs, such as a storm caused blowdown (e.g., Drouineau *et al.*, 2000), especially when significant financial losses are at issue. Given the natural propensity of managers to manage, and the future likelihood of more frequent and destructive disturbance, the potential increases for maladaptive management response to disturbance recovery. In other words, we are at greater risk than ever before of making matters worse by intervening, unless our intervention is based on understanding the dynamics of disturbances in forested ecosystems.

What Are Disturbance Dynamics of Forested Ecosystems?

The classic definition of disturbance is that of White and Pickett (1985): "A disturbance is any relatively discrete event in time that disrupts ecosystem, community, or population structure and changes resources, substrate availability, or the physical environment." In the literature, the agent of disturbance is often confused or confounded with the damage caused by that agent. Thus a windstorm causes trees to blowdown; the windstorm is the disturbance (agent) and blowdown is an effect. Of course, we have to recognize that effects themselves can have cascading effects, which can be analyzed with the damage effect as the disturbance agent. Keeping with the blowdown example, trees that are tipped over causing soil movement may, if on a slope, initiate mass wasting that is a disturbance.

Some disturbance ecologists limit disturbance to physical agents, or incidentally biotic agents such as the example above. Thus invasive exotic plant species, insect epidemics or outbreaks, or herbivory by large mammals would not fall within the realm of disturbance events (Sousa, 1984). More generally, however, the tendency is to regard any exogenous perturbation as disturbance. Thus any exogenous or abiotic stress would qualify as a disturbance, usually in the sense of chronic or diffuse stress versus acute or discrete disturbance events. In the environment of today and the likely future, these distinctions will likely be of interest only to researchers.

Most research on disturbance agents has focused on relatively common, thus small frequent disturbance (SFD) events. A recent spate of large-scale natural disasters has focused greater attention on large, infrequent disturbances (LID) such as wildfires, winter windstorms, and floods. A logical question is whether ecosystem response to SFDs and LIDs are the same in terms of response to extent, intensity, or duration? It appears that at least in some cases, LIDs exceed the capacity of internal accommodation to disturbance through resistance or resilience mechanisms (Romme *et al.*, 1998). Thus a novel threshold response in an ecosystem could result from a new disturbance, a more intense or longer duration event than has ever been experienced, or because endogenous accommodation mechanisms have been altered. An example of a new disturbance would be acute air pollution emissions from combustion sources; greater intensity meteorological events such as hurricanes are likely under global climate change; and fire suppression causing homogenization and buildup of fuels has caused shifts in fire regime from frequent, low-intensity ground fires to infrequent, high-intensity stand replacing crown fires (Covington and Moore, 1994).

Most abiotic disturbances are meteorologic or climatic events. Windstorms, including downbursts and tornadoes (Peterson, 2000), and their effects are well-studied and often incorporated into forest management prescriptions. Hurricanes and typhoons have been similarly studied, although to a lesser extent due to their lesser frequency (Boose *et al.*, 1994). Ice storms can have devastating effects on forests, although the affected area may be small relative to other infrequent events such as hurricanes (Smith, 2000). Climatic events such as drought may be diffuse, lasting several years to a decade or more. Drought is usually a recurring stress, such as late summer drought in forests that depend on moisture stored in the soil from winter precipitation. Periodic acute droughts predispose individual larger trees to insects and disease but may kill smaller trees. Climate change scenarios posit that forests in some areas that are not well adapted to drought conditions will be impacted by higher temperatures, lower or more variable rainfall, or both (Dale *et al.*, 2001). Similarly fire is a meteorologic/climatic disturbance agent. Climate and weather certainly determine productivity levels and to some extent species composition, hence fuel loads. Natural fire ignitions are by lighting, usually in conjunction with thunderstorm activity. Initiation and spread are a function of weather, primarily precipitation but also relative humidity, temperature, and wind velocity.

Geologic disturbance agents include volcanoes, floods, and mass movements such as landslides, snow avalanches, mass wasting, and soil erosion, transport, and deposition. Coastal forests are subject to disturbances from coastal processes such as subsidence, dune movement, and mass wasting. Riverine forests are highly dynamic environments; flooding disturbances in these systems includes both inundation of forests or individual trees by floodwaters, as well as geomorphologic changes such as meandering, changes of course, creation of oxbow lakes, etc.

Biotic disturbance agents include insects and diseases, invasive plants, and mammalian herbivores. As noted above, some disturbance ecologists would not include these as disturbance agents but in practice they are regarded both by the public and by scientists as disturbances when they exhibit threshold effects on ecosystems. Thus "normal" levels of infestation or herbivory are not disturbances and in many cases, thresholds are exceeded only because of human activity. For example, removal of predator species such as wolves has been responsible for increases in mammalian herbivory in many forested ecosystems, to such an extent that they can be regarded as disturbance agents. Another biotic disturbance agent that almost rivals humans in terms of the ability to alter ecosystems is the beaver (Naiman *et al.*, 1986).

Disturbance as a causal agent has temporal and spatial dimensions, which lead to some emergent properties: intensity (of the force of disturbance), scale (area over which it operates), and frequency (number of events per unit time). Disturbances in forested ecosystems usually create open or altered areas or patches, although effects of some disturbances are so diffuse that patches are not obvious (White and Pickett, 1985). Patches are often called gaps by forest ecologists, especially those conditioned to think in terms of patches created by single treefalls. The temporal and spatial pattern of these open or altered patches results in a disturbance regime. The severity of a disturbance is a measure of the effect of the disturbance on the forest; together intensity and severity are the magnitude of a disturbance event. For example, even a high intensity fire in a fire-adapted pine forest might be of low severity if the fire only consumed fuel on the ground and did not become a crown fire. On the other hand, even a low intensity ground fire that started in a pine stand and burned through a bottomland hardwood forests in a drought year might severely impact the wetland forest. Disturbance regimes result from temporal and spatial patterns of open or altered patches. Distribution and frequency of events, area disturbed, magnitude (intensity and severity), recurrence of disturbance, and seasonality are all factors in describing disturbance regimes (White and Pickett, 1985).

The dynamics of the created patches have also been studied, although not as extensively as patch creation (Pickett and White, 1985). Factors contributing to patch dynamics include disturbance regime, whether and how quickly patches expand or close, and the landscape context of patches (relationship one to another and to the undisturbed matrix, flows of organisms, materials, and energy among patches). The fate of disturbed patches in forested ecosystems is best understood in terms of stand dynamics, as long as the patches are large enough that most trees beginning growth within the patch are not competing with surrounding trees (Oliver, 1980; Oliver and O'Hara, 2004).

How can we incorporate disturbance dynamics into forest management?

Disturbances rarely can be avoided indefinitely, although the most destructive or costly effects may be avoided or mitigated through effective management. An adaptive management strategy will have four components: (1) manage the initial conditions of the system, prior to disturbance; (2) manage the disturbance event; (3) manage the system after the disturbance; and (4) manage the recovery process (Dale *et al.*, 1998; Beatty and Owen, 2004). The greatest value will come from managing the system before the event and conditioning it to avoid threshold events. Most of our experience, particularly with large infrequent disturbances, is in managing (or frequently mismanaging) the recovery.

The initial conditions of species composition and stand structure to a large extent determine the nature of the response to a particular disturbance event. Initial conditions, however, are a function of boundary conditions and history that includes stresses and past disturbances, especially time since disturbance relative to recovery processes. The stability, resilience, and resistance of a stand in the face of disturbance are a result of these initial system conditions and the nature of the disturbance (intensity, duration). A current example of managing initial conditions is occurring in all fire-prone forested ecosystems in the United States. Years of fire suppression and attempted fire exclusion have altered fuel loads in many forests so as to alter the fire regime. In some cases this has meant changing from a relatively benign ground fire regime to a stand replacement fire regime. Simply allowing fire, whether wildfire or prescribed burning, back into the stands is not feasible due to the altered fuel loads, especially the live fuels of dense understory trees. Nevertheless, altering initial stand conditions will perhaps mitigate the effects of wildfire disturbances in the future. Another example of altering initial conditions is the effort in some Western European countries to convert Norway spruce plantations to other species, in hope that the resulting stands will be more stable in the face of windstorms (Hahn *et al.*, 2004).

Disturbances can be managed by doing nothing (no action alternative), attempting to prevent the disturbance, or manipulate and channel the effects. Sometimes the doing nothing is all that can be done: some disturbances such as volcanic eruptions are beyond our technology. Under some circumstances, wildfire can be ignored. Preventing disturbances may be feasible, at least when the costs of prevention are perceived to be lower than the costs of the disturbance. Thus some disturbances such as flooding or coastal erosion are prevented in places by engineering structures, in order to protect human life and valuable property. In a sense, laws to protect some rare or endangered species are to prevent disturbances from affecting them and their habitat. Managing disturbances by manipulating effects is certainly part of the process of restoring natural disturbance regimes that have been disrupted by human intervention. Again fire provides a ready example: fire cannot be re-introduced after many years of suppression because of the fuels that developed. Mechanical fuel reduction followed by dormant season prescribed burning to reduce fuels is a way to manipulate the intensity and severity of fire before normal growing season fires are introduced.

Managing the system after disturbance and managing the recovery are really one process, arbitrarily separated to emphasize short-term management immediately after a large infrequent disturbance and the longer-term recovery of the system between events. Immediately after a natural disaster, the media, public, and politicians clamor to do something when the best policy is to do very little except protect human health and safety and restore infrastructure. Salvage logging following meteorological events may be justified to recover value, although due to price effects on timber markets it may not pay for the harvesting and transportation costs. Long-term management should enhance natural renewal processes, not inhibit them. To do so successfully requires an understanding of disturbance dynamics, including what should be left in a disturbed area, what should be removed, what should be excluded, and what should be added.

Literature Cited

Beatty, S. W. and Owen, B. S. 2004. Incorporating disturbance into forest restoration. Chapter 4 in Stanturf, J.A. and P. Madsen, eds. Restoration of Boreal and Temperate Forests. CRC Press, Boca Raton, FL. (in press).

Boose, E. R., Foster, D. R., and Fluet, M. 1994. Hurricane impacts to tropical and temperate forest landscapes. Ecological Monographs 64(4), 369–400.

Covington, W.W. and Moore, M.M. 1994. Southwestern ponderosa forest structure and resource conditions: changes since Euro-American settlement. Journal of Forestry 92, 39.

Dale, V. H., Joyce, L. A., McNulty, S., Neilson, R. P., Ayres, M. P., Flannigan, M. D., Hanson, P. J., Irland, L. C., Lugo, A. E., Peterson, C. J., Simberloff, D., Swanson, F. J., Stocks, B. J., and Wotton, M. 2001. Climate change and forest disturbances. BioScience 51(9), 723–734.

Drouineau, S., Laroussinie, O., Birot, Y., Terrasson, D., Formery, T., and Roman-Amat, B. 2000. Joint evaluation of storms, forest vulnerability and their restoration. European Forestry Institute Discussion Paper 9, Joensuu, Finland.

FAO. 2002. Food and Agriculture Organization (FAO), Proceedings expert meeting on harmonizing forest-related definitions for use by various stakeholders, Rome, 22–25 January 2002, FAO, Rome.

Goudie, A., The Human Impact on the Natural Environment, MIT Press, Cambridge, MA, 1986.

Hahn, K., Emborg, J., Larsen, J.B., and Madsen, P. Forest rehabilitation in Denmark using nature-based forestry. Chapter 19 in Stanturf, J.A. and P. Madsen, eds. Restoration of Boreal and Temperate Forests. CRC Press, Boca Raton, FL. (in press).

Naiman, R. J., Melillo, J. M., and Hobbie, J. E. 1986. Ecosystem alteration of boreal forest streams by beaver (Castor canadensis). Ecology 67(5), 1254–1269.

Oliver, C. D. 1980. Forest development in North America following major disturbances. Forest Ecology and Management 3, 153–168.

Oliver, C. D. and O'Hara, K. L. 2004. Effects of restoration at the stand level. Chapter 3 in Stanturf, J. A. and P. Madsen, eds. Restoration of Boreal and Temperate Forests. CRC Press, Boca Raton, FL. (in press).

Paine, R. T., Tegner, M. J., Johnson, E. A. 1998. Compounded perturbations yield ecological surprises. Ecosystems 1(6), 535–545.

Peterson, C. J. 2000. Catastrophic wind damage to North American forests and the potential impact of climate change. The Science of the Total Environment 262, 287–311.

Pickett, S. T. A and White, P.S. 1985. Patch dynamics: A synthesis. Chapter 21 in Pickett, S.T.A and White, P.S., eds. The Ecology of Natural Disturbance and Patch Dynamics. Academic Press, New York.

Romme, W. H., Everham, E. H., Frelich, L. E., Moritz, M. A., and Parks, R. E. 1998. Are large, infrequent disturbances qualitatively different from small, infrequent disturbances? Ecosystems 1(6), 524–534.

Smith, W. H. 2000. Ice and forest health. Northern Journal of Applied Forestry 17(1), 16–19.

Sousa, W. P. 1984. The role of disturbance in natural communities. Annual Revue of Ecology and Systematics 15, 353–391.

Stanturf, J. A., Kellison, R. L., Broerman, F. S., and Jones, S. B. 2003. Productivity of southern pine plantations: Where are we and how did we get here? Journal of Forestry 101(3), 26–31.

Stanturf, J. A. 2004. What Is Forest Restoration? Chapter 1 in Stanturf, J. A. and P. Madsen, eds. Restoration of Boreal and Temperate Forests. CRC Press, Boca Raton, FL. (in press).

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